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MODELS OF MAINTENANCE RESOURCES INTERACTION: PEACETIME OPERATIONS

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The primary objective of this study was to provide the Air Force with models of the interactive effects of manpower, spares, and support equipment for a current operational system. Initial tasks established the peacetime data requirements of a current operational fighter, the available sources of data, and the critical variables for the Logistics Composite Model (LCOM) simulations. The simulated environments relate directly to the Air Force base level data, e.g., flying profiles, mission, and resource allocation levels. The majority of the data for this study were obtained from the following sources: (a) Air Force and contractor publications, (b) Maintenance Data Collection (MDC)

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system, and (c) structured interviews with operations and maintenance personnel. Regression models were developed for significant LCOM variables. The LCOM and the regression models of interaction developed in this study have applicability to design and management issues.

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SUMMARY

Objective

The primary objective was to establish the interactive effects of maintenance manpower, spares, and support equipment for a current operational fighter aircraft on peacetime sortie generation capability.

Background

The Air Force has a recurring need to estimate the spares level, the ground support equipment, and the maintenance manpower necessary to support desired flying activities in various Air Force organizations. The AFHRL Maintenance Manpower Model, incorporating the Logistics Composite Model (LCOM), provides a technology for forecasting the maintenance manpower requirements for a weapon system. Currently, spares and support equipment provisionings are developed separately and incorporated into the LCOM as constants. Changes in the spares and support equipment levels have been shown to require changes in the manpower forecasts. The converse also is true. Therefore, an advancement on the modeling technology is needed to provide for the interactive forecasting of these resources.

Approach

The three major steps of approach included identifying the essential variables and data resources, conducting sensitivity analysis based on an LCOM simulation plan, and developing regression equation models. The basic data sources were Air Force and contractor publications, Air Force maintenance data, and structured interviews with operations and maintenance personnel. Software was developed to incorporate current failure data, to reflect peacetime flying scenarios, and to incorporate organization structure, scheduled and unscheduled maintenance, and procedure logic data.

Specifics

Method. The simulation design isolated the following five input (independent) variables for study: (a) three peacetime aircraft utilization rates, (b) two maintenance concepts of with and without cannibalization, (c) three spares resources levels, (d) three mapower resource levels, and (e) three support equipment resource levels.

Sensitivity analyses of the 183 simulation runs established that all dependent variables should be considered for regression model development. Separate regression analyses were conducted on (a) spares, manpower, and utilization rates, (b) effects of cannibalization, (c) spares, manpower, support equipment, and utilization rates, and (d) contribution of resource interaction terms in the regression models.

Findings and Discussion. The findings indicate that regression equations with interaction terms have greater predictive power than equations without the interaction terms for the conditions in which support equipment variations are considered in addition to those of manpower and spares. Of the 35 dependent variables examined, 9 were significantly impacted by cannibalization. Regression models were developed for these nine variables. (Cannibalization is especially influential when the supply fill-rate for the baseline condition is not 100%.)

Because sortie-demand rates differ during peacetime and war, the measures "operationally ready" and "non-operationally ready due to supply" are more realistic indicators of readiness than are sorties accomplished during peacetime. Wartime flying scenarios should be simulated and measures such as sorties accomplished and missions accomplished should be examined for effects of resource variations.

Conclusions/Recommendations

The interactive effects of maintenance manpower, spares, and support equipment on the peacetime readiness of fighter aircraft units were demonstrated. The impact of other variables (utilization rates and cannibalization) on these interactions also was studied. The technology employed in this effort has general applicability in the planning and management of Air Force Systems.

It is recommended that the improved manpower modeling technology be used for (a) answering "what if" questions, (b) eliminating total restudy, (c) identifying and justifying "spare" capacity of manpower, spares, or support equipment resources, and (d) determining existing readiness capability.

PREFACE

This technical report is one of a series of reports under Contract No. F33615-77-C-0074, Development of Models of Maintenance Resources Interaction. Five of these were published as McDonnell Douglas Corporation reports. Two of them are AFHRL-TR-82-19 and AFHRL-TR-82-20.

The study was directed by Logistics and Human Factors Division, Air Force Human Resources Laboratory, Wright-Patterson Air Force Base, Ohio. The Air Force Human Resources Laboratory Project Scientist was Dr. Ross L. Morgan.

This research was documented under Work Unit 1710-00-23, "Development of Models of Maintenance Resources Interaction." Frank A. Maher was the Work Unit Scientist and Air Force Contract Monitor. The McDonnell Douglas Corporation Program Manager was Carl F. Asiala.

The authors wish to extend their appreciation to the many people within the government and private industry who contributed their time and expertise throughout the course of this research.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

I. INTRODUCTION

PROBLEM

In the past, weapon systems designers strove for the highest level of equipment performance possible, using whatever advanced technology might be achievable within the state-of-the-art and the constraints imposed by the development schedule. However, severe restrictions have been imposed on the defense budget, and now greater consideration is put on cost in weapons design, development, and support. The emphasis on cost of ownership of weapon systems has added a dimension to both the design process and the operational use of a weapon system that challenges the best efforts of the industrial and military communities alike.

The expenditures for new developments and procurements have steadily decreased during the late 1960s and early 1970s, and operations and maintenance (O&M) costs have steadily increased. In recent years, the O&M costs have stabilized with major appropriation cuts in manpower. The growing concern with cost of ownership and readiness issues of weapon systems has spawned greater efforts to forecast accurately O&M and military personnel costs to which manpower, support equipment, and spare parts are major contributors. For this reason, estimating the spares level and the maintenance manpower required to support a given level of flying activities in any particular Air Force organization poses a continuing problem to all levels of management.

As new aircraft enter the weapons inventory and operating and maintenance procedures change, there is a recurring need for reliable estimates of the spares, support equipment, and manpower resources necessary to support efficiently the desired level of operational activity. Such estimates enable managers to allocate personnel and material resources to new as well as existing organizations, thus ensuring combat readiness. The Air Force has already developed technologies, such as Mod-Metric (References 1 and 2), to provision for spares. However, interrelationships of resource classes such as spares, support equipment, and manpower have not been adequately identified. Such interrelationships must be defined and understood before efficient determination or tradeoff of resource levels can be considered.

Currently, manpower projections are developed separately from spares and support equipment provisioning requirements. The Air Force Human Resources Laboratory (AFHRL) Maintenance Manpower Model, incorporating the Logistics Composite Model (LCOM), provides a technology for forecasting the maintenance manpower requirements for a new weapon system (Reference 3). Spares and support equipment provisionings for the same weapon system are developed separately and incorporated into the LCOM as constants. Changes in the spares and support equipment levels have been shown to require changes in the manpower forecasts, and the converse is also true. Therefore, an advancement in modeling technology is needed to provide for the interactive forecasting of these resources.

The Maintenance Manpower Model is a numerical, digital simulation model designed to process USAF base level data related to aircraft maintenance and support functions, illustrated in Figure 1. The model is capable of estimating maintenance manpower requirements of an operational aircraft squadron or wing at any specified level of flying activity (References 4 through 8). It was developed by AFHRL and incorporates the LCOM (References 9 through 11). A validation study of the LCOM is reported in Reference 12. Extensions and improvements of the model to increase its capabilities are underway at AFHRL, the Air Force Management Engineering Agency (AFMEA), and at McDonnell Douglas Corporation (Reference 13). The simplified LCOM concepts forming the basis of this study effort are summarized in Reference 14.

STUDY OBJECTIVE

The objective of this study was to establish the interactive effects of manpower, spares, and support equipment for a given weapon system in a peacetime environment. The initial ground rules for determining the resource interactions were that at least three variations in flying programs, as well as maintenance concepts including cannibalization and deferred maintenance, were to be considered for the F-15 operational fighter weapon system, illustrated in Figure 2.

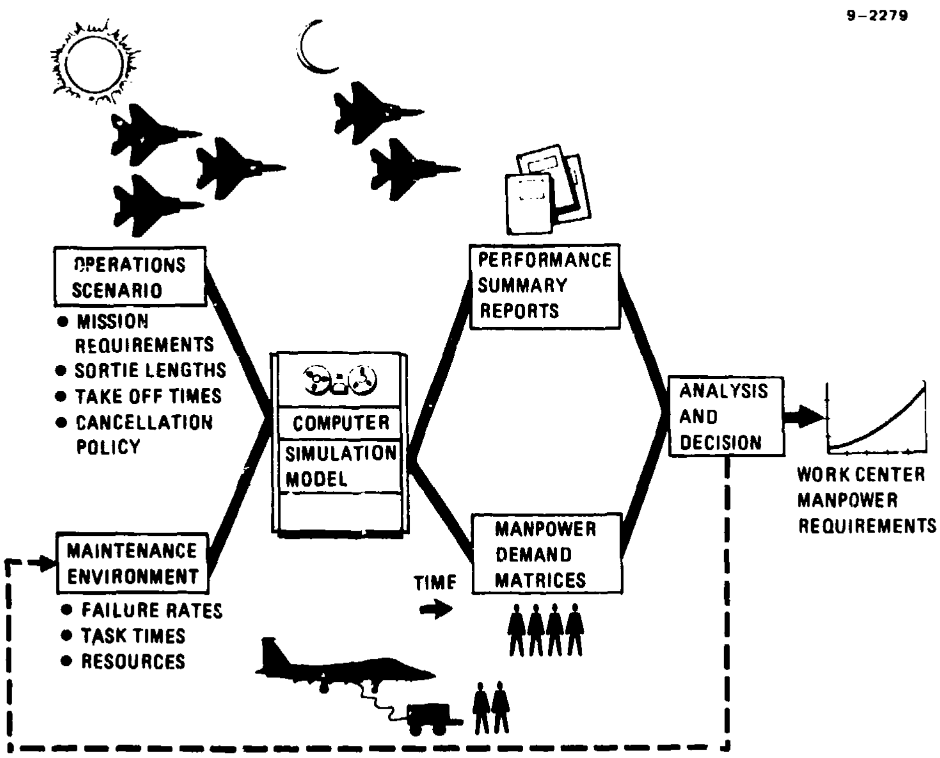

FIGURE 1 LOGISTICS COMPOSITE MODEL

FIGURE 2 CURRENT OPERATIONAL FIGHTER WEAPON SYSTEM

II. APPROACH

The approach for development of models of maintenance resources interaction is summarized in Table 1. Several initial tasks to accomplish the study objective were (a) determine the essential variables for the F-15 fighter wing in a peacetime environment, (b) identify and define data sources, (c) develop an experimental simulation plan, (d) perform a sensitivity analysis, and (e) develop regression models of interactions. Table 1 also denotes the interim reports (References 14, 15, and 16) in which each research task is documented.

DEFINITION OF DATA REQUIREMENTS

Several publications considered relevant to this study were collected in an initial literature review (References 17 through 54). Three previous Air Force Institute of Technology (AFIT) theses have addressed LCOM estimation of maintenance manpower requirements: (a) Green and Rumple (1975) constructed an LCOM simulation to evaluate the effects of alternative operational, maintenance, and supply policies on remotely piloted vehicle (RPV) maintenance manning (Reference 17); (b) Fritz and Yates (1975) used LCOM to simulate the interaction of the RPV, the launch aircraft, and the recovery helicopter (Reference 18); and (c) DeGovanni and Douglas (1976) used LCOM for estimation of F-15 peacetime maintenance manpower requirements (Reference 19).

Tactical Air Command (TAC) used LCOM to estimate maintenance manpower requirements for its F-4, A-7, A-10, F-15, and F-16 aircraft (Reference 20). However, TAC conducted the majority of these studies using a wartime operational environment and devoted limited attention to a peacetime environment. Each of these previous TAC LCOM studies simulated concurrent flying and maintenance activity; that is, aircraft maintenance was performed only on days of scheduled flying operations. In a wartime environment, this practice is acceptable since aircraft missions are scheduled 7 days each week. However, this practice has one major drawback. If a high level of flying activity is scheduled, the aircraft maintenance organization may, at times, become overloaded with work. This causes a temporary decrease in flying activity until the maintenance organization clears out the backlogged work.

In a peacetime environment, flying operations are normally scheduled Monday through Friday. During high levels of flying activity, the maintenance organization continues to perform its functions on weekends in order to alleviate backlogged work. In this manner, the maintenance complex can usually keep pace with the weekly flying operations, and the day-to-day level of flying activity remains fairly constant. Since few LCOM studies have addressed the peacetime operational environment, the initial study task was to define essential LCOM simulation data requirements for peacetime operation.

9-2722

TABLE 1 APPROACH FOR DEVELOPMENT OF MODELS OF MAINTENANCE RESOURCES INTERACTION

OBJECTIVES	APPROACH
1 – DEFINE ESSENTIAL LCOM SIMULATION DATA REQUIREMENTS FOR PEACETIME ENVIRONMENT	TASK 1 – DETERMINE CRITICAL VARIABLES FOR CURRENT OPERATIONAL FIGHTER SYSTEM IN PEACETIME ENVIRONMENT TASK 2 – DEFINE AVAILABLE DATA RESOURCES FOR SELECTED OPERATIONAL FIGHTER SYSTEM (REFERENCE 14)
2 – ESTABLISH IMPACT OF VARIATIONS OF PEACETIME MANPOWER, SPARES, AND SUPPORT EQUIPMENT RESOURCE LEVELS	TASK 3 – DEVELOP SIMULATION PLAN BASED ON INITIAL LCOM RUNS, EXPERIMENTAL DESIGN AND STATISTICAL ANALYSES TASK 4 – PERFORM SENSITIVITY ANALYSIS, WHICH INCLUDES SOFTWARE MODIFICATIONS, LCOM SIMULATIONS, AND DATA ANALYSIS (REFERENCE 15)
3 – ESTABLISH THE INTERACTIVE EFFECTS OF MANPOWER, SPARES, AND SUPPORT EQUIPMENT.	TASK 5 – DEVELOP TWO SETS OF REGRESSION EQUATION MODELS FOR MANPOWER, SPARES AND AIRCRAFT UTILIZATION RATE INTERACTIONS, AND FOR MANPOWER, SPARES, SUPPORT EQUIPMENT, AND AIRCRAFT UTILIZATION RATE INTERACTIONS (REFERENCE 16)

The major variables considered in performing an LCOM analysis were (a) weapon system definition, (b) maintenance requirements, and (c) operations requirements. Since the LCOM evaluates the interaction of activities in the simulated environment, it is imperative that all aircraft maintenance work centers within an operational wing be included in the model. A summary of the essential input variables is contained in Table 2.

Data bases for weapon systems vary in size and scope. Older weapon systems generally have large operations and maintenance data bases. Newer system or systems under development have either limited or no historical data. Each requires a different data acquisition approach. Primary sources for current fighter data include various staff elements of the Tactical Air Command and its operational bases. Secondary sources are Headquarters-Air Force and the Air Force Logistics Command. Most of the data for this study were obtained from (a) Air Force and contractor publications, (b) Air Force Maintenance Data Collection system (Reference 23), and (c) structured interviews with operations and maintenance personnel. Table 2 depicts the relationship of essential variables to data sources approach used in this study.

AFM 66-1 stipulates that a maintenance data collection system will be used to enhance maintenance management. This system provides a means of collecting vast amounts of data generated during base level maintenance activities. The system begins at the maintenance work center level with the completion of an AFTO Form 349 by the maintenance technician. This form describes all maintenance actions taken by the maintenance technicians as they repair or replace aircraft components (Reference 23). As the AFTO Form 349s are completed and assembled, the data are keypunched, compiled, and placed on computer tape. This tape (ABD6DA) usually is a 6-month summary tape and is the main source of base level maintenance data available to the analyst when building the LCOM data package.

FORTRAN data processing programs have been developed to structure AFM 66-1 maintenance data in a form that can be used in developing task data input for an LCOM simulation (Reference 6). These programs have been updated recently by AF Maintenance and Supply Management Engineering Team (AFMSMET), Wright-Patterson AFB, Ohio.

A significant source of valid maintenance data was the experienced maintenance personnel of the using command. Maintenance concepts and policies were obtained from the Director of Maintenance Engineering, Deputy Chief of Staff, Logistics (LG) of the operational command. Hands-on maintenance knowledge of the weapon system was obtained from the base maintenance specialists and technicians at the Chief of Maintenance level. The Maintenance Management Information and Control System (MMICS) (Reference 54) and the Production Analysis section within the Chief of Maintenance organization were also valuable sources of data.

TABLE 2 RELATIONSHIP OF ESSENTIAL VARIABLES TO DATA SOURCE APPROACH

9-2724

LCOM ESSENTIAL VARIABLES	DATA SOURCE APPROACH		
	AF AND CONTRACTOR PUBLICATIONS	MAINTENANCE DATA COLLECTION (MDC) SYSTEM	STRUCTURED INTERVIEWS
WEAPON SYSTEM DEFINITION			
1. COMPONENTS	X		
2. FAILURE PARAMETERS			
a. DEFINITION	X	X	
b. LEVELS		X	
OPERATIONAL DATA			
1. MISSION TYPE	X		X
2. SORTIE LENGTH			X
3. PRIORITIES			X
4. AIRCRAFT STANDARD CONFIGURATION	X		X
5. FLIGHT SIZE			X
6. LEAD TIME			X
7. CANCEL TIME			X
8. LAUNCH TIME			X
9. SPARE AIRCRAFT AVAILABILITY			X
10. WEATHER	X		X
MAINTENANCE DATA			
1. CLASS			
a. UNSCHEDULED	X	X	
b. SCHEDULED	X	X	X
2. TYPE			
a. CODE DEFINITION	X		
b. FREQUENCY		X	
3. RESOURCE			
a. ORGANIZATION STRUCTURE	X	X	X
b. AFSC	X	X	X
c. CREW SIZE		X	X
d. TASK TIME		X	X
e. SUPPORT EQUIP.	X		X
f. PARTS			X

NOTE: X IMPLIES THAT THE DATA SOURCE IS APPLICABLE TO THE LCOM ESSENTIAL VARIABLE CATEGORY.

Historical data and statistical trends showing the unit's maintenance performance/capabilities were obtained from these sources and were prime areas for investigation.

Operations data were also readily available from the using command's operations personnel. Operational doctrine and concepts involving the aircraft were obtained from the appropriate staff element within the Deputy Chief of Staff, Operations (DO). Information on actual wartime utilization policies governing deployment concepts, flying rates, attrition, weapon loads, alert requirements, flight sizes, mission types, and launch times were acquired from applicable Air Force programs and publications and discussions with DO staff or experienced operational crews. The structured interview format developed and employed for this study is illustrated in Reference 14.

An essential activity, prior to software development, was the definition of data requirements based on available data sources. Reference 14 provides the data requirements, the available sources of data, and the recommended sources for the LCOM simulations. The following paragraphs present an overview of the study parameters.

Critical LCOM Input Parameters - The major LCOM input parameters were (a) peacetime flying programs, (b) maintenance concepts, and (c) spares, manpower, and support equipment resources. All aircraft maintenance work centers within a 72 Unit Equipped (UE) wing were represented in the model. The following levels of each parameter were examined:

1. Peacetime flying program with utilization rates of approximately 10, 20, and 30 (utilization rate is defined as flying hours per month for an aircraft).

2. Maintenance concepts with cannibalization allowed and cannibalization disallowed.

3. Spares resources: (a) baseline defined as the spares resources required to have 95-100% sorties accomplished with an average non-operationally ready rate due to supply (NORS) not to exceed 5% and (b) at least two levels of constrained spares supply below the baseline level so that linear or nonlinear relationships could be examined.

4. Manpower resources: (a) baseline defined as manpower resources to accomplish the baseline spares resources criteria and (b) at least two levels of constrained manpower levels below the baseline level.

5. Support equipment resources: (a) baseline defined as support equipment resources to accomplish an average NORS criterion of 5%, while holding spares and manpower at established baseline values and (b) two levels of constrained support equipment resources below the baseline level.

Critical LCOM Output Variables - The LCOM output variables were grouped into categories of operations, aircraft, manpower, shop repair, spares supply, and support equipment. Based on the established critical input variables for this study, the LCOM output variables listed in Table 3 were considered critical for the development of models of maintenance resources interaction. The numerical identifier and nomenclature are compatible with that existing in LCOM II documentation (Reference 11). Definitions of these critical parameters are provided in References 10 and 11. These references also describe additional output parameters for the LCOM. However, these additional parameters were not related to this study's objective.

USAF Base Data Sources

Available data sources for the selected current operational fighter, especially base level sources, were reviewed for definition of the simulated environment. These data were necessary to establish such variables as flying profiles, missions, resource allocation levels, and realistic back-order days. The primary available data sources were (a) Air Force Development Testing and Evaluation (AFDT&E) at Edwards AFB, California, (b) Tactical Fighter Training, (c) Continental United States (CONUS) AFBs, and (d) European AFBs. A major objective of this study was the simulation of an operational fighter wing. Therefore, the majority of detailed information was compiled for operational fighter wings located in CONUS and Europe. However, comparisons of the data from the AFDT&E aircraft at Edwards AFB and training wings provided useful background information on the weapon system.

Data Base Software - The computer hardware and software necessary to perform this study were readily available. However, data base management techniques had to be defined and a methodology established preceding actual application of the LCOM. Interactive computer procedures were used to create a representative and functionally accurate data base for a current fighter aircraft (Reference 55).

Weapon System Definition

Initially, the aircraft is described using the work unit codes (WUC) defined in the applicable Air Force Work Unit Code Manual. The WUC provides a standardized method of designating the individual parts that comprise the weapon system. Each part can be assigned an alphanumeric code $\leq$ 5 symbols. The first 2 symbols define the class of equipment; the third, the particular system; the fourth, the component within the system; and the fifth, the part within the component. There were 411 WUCs examined in this study (Reference 14).

TABLE 3 LIST OF CRITICAL LCOM OUTPUT VARIABLES

CATEGORY	NO.	DEPENDENT VARIABLES TITLE	A	B	C
OPERATIONS	3	Percent accomplished - Missions	•	•	•
	8	Percent accomplished - Sorties	o	•	o
AIRCRAFT	15	Percent on sorties (including Alert)	o		o
	16	Percent in unscheduled maintenance	o		o
	17	Percent in scheduled maintenance	o		c
	18	Percent in NORS	o		o
	19	Percent in mission wait status	o		o
	20	Percent in service plus waiting	o	•	o
	21	Percent in operationally ready	o		o
	22	Average aircraft post-sortie time (hours)	•		•
	23	Average number of sorties per aircraft per day	o		o
	24	Flying hours	•	•	•
	TS	Average aircraft pre-sortie time (hours)	•		•
MANPOWER	28	Percent utilization	o		o
	29	Manhours used (X100)	o		o
	30	Percent unscheduled maintenance	•		•
	31	Percent scheduled maintenance	•		•
	33	Number of men demanded	o	•	o
	34	Percent men available (Prime)	•		•
	39	Percent demands not satisfied	o		o
	40	Simulated maintenance manhours per flying hour	o	•	o
SHOP REPAIR	44	Number of repairable generations	•	•	•
	45	Percent base repair	•		•
	46	Percent depot repair	•		•
	47	Average base repair cycle	o		o
	48	Percent active repair	o		o
	49	Percent white space	o		o
SPARES SUPPLY	55	Percent fill rate	o		o
	56	Number of backorder days	o		o
	57	Number of units demanded	o	•	o
	58	Percent units off-the-shelf	•		•
	61	Percent of demands not satisfied	o		o
	62	Number of cannibalizations		•	
	63	Number of items on backorder	•		•
SUPPORT EQUIPMENT	71	Equipment percent used - unscheduled maintenance			•
	72	Equipment percent used - scheduled maintenance			•
	73	Equipment percent unused			•
	74	Number of backorder days			•
	75	Number of units demanded	o		o
	79	Equipment percent demands			•

COLUMN A = SPARES x MANPOWER WITHOUT CANNIBALIZATION
B = SPARES x MANPOWER WITH CANNIBALIZATION
C = SPARES x MANPOWER x SUPPORT EQUIPMENT

• TYPE 1 = LINEAR AND QUADRATIC COMPONENTS OF MAIN EFFECTS

o TYPE 2 = TYPE 1 PLUS INTERACTIONS OF MAIN EFFECTS

Failure Parameters - The Maintenance Data Collection system tape for each tactical fighter wing defines failure parameters for components in the corrective maintenance networks. The tape contains maintenance data for a specified time period related to sorties and flying hours generated. The procedures necessary to extract useful maintenance data from the tape are described in References 4 and 5. These references also illustrate the method for computing the LCOM failure parameters of the mean sorties between maintenance actions (MSBMA), mutually exclusive probability (E), and nonmutually exclusive probability (G). The actual failure parameters used in this study are set forth in Reference 15. Each component failure clock, its corresponding MSBMA, and decrement value are contained in the data base.

Aerospace Vehicle Status Codes - The terminology used by the Air Force to report aerospace vehicle status has been changed to prevent confusion with unit readiness for war. The terms used in Table 4 were selected by a DoD tri-service work group to ensure standard terminology for all services. The effective date of change was 1 October 1977. Since the LCOM has not been revised to reflect these changes in terminology, the nomenclature used in the LCOM was also used in this report (see Table 3).

Peacetime Operations

The peacetime operations scenario for a current operational fighter is governed by the graduated combat capability concept (GCC) (References 52 and 53). The GCC recognizes that aircrews must fly certain sorties to train for each assigned task/mission, including using specialized weapons on unique missions, and that the degree of difficulty and training complexity for each task/mission varies.

Accordingly, a specified amount of flying must be provided to train for each assigned task/mission. GCC further recognizes that available resources are limited. For this reason, desired combat capabilities have been assigned priorities, thus acknowledging that a resource limited unit can be fully trained in only the higher priority tasks/missions. The training terms, their abbreviations, requirements, and criteria applicable to the GCC are defined in Reference 14.

Peacetime Scenario - Based on structured interviews (using the format contained in Reference 14) at CONUS and European AFBs, the following parameters were established for guidance and input during LCOM simulation of a current fighter's maintenance activities in a peacetime environment. These parameters were used in designing work flow processes and sortie scheduling.

Unit Size and Organizational Structure - The initial peacetime LCOM results should consider estimating the manpower requirements to support a 72 UE wing. However, if additional studies are performed, optional study parameters are two different sizes of wings: (1) a 72 UE wing capable of deployment to two, separate, self-sustaining operational locations with strengths of 48 UE and 24 UE, and (2) a 54 UE wing capable of deployment to separate, self-sustaining operational locations of 36 UE and 18 UE strength. The wing maintenance structure should be as outlined in AFM 66-1. Production-oriented maintenance organization (POMO) concepts should be considered for future studies.

Aircraft Configuration - A current operational fighter aircraft configuration is best described by a combination of the fuel and ordnance codes, Reference 14. The aircraft configuration for peacetime simulation is directly related to the mission types. The majority of peacetime missions use the aircraft configuration B + 6C, which is full internal fuel and a 600-gallon centerline tank plus a full gun load in the cold gun mode.

Missions - The majority of mission types relate directly to GCC requirements. A breakdown of missions flown at the CONUS and European AFBs by mission type is shown in Table 5. The percentages shown do not necessarily dictate sortie scheduling, since more than one mission type of GCC requirement, with some exceptions, can be accomplished in a single sortie. In addition, certain geographic limitations, e.g., CONUS versus Europe, will dictate exceptions to satisfying GCC requirements. Other peacetime missions, such as alert at a European AFB or Weapon System Evaluation Program (WSEP) at a CONUS AFB, will have specific maintenance and scheduling criteria to be met. Review of the GCC requirements, aircraft configurations, and additional peacetime missions indicate that, if sorties are scheduled by the following mission categories for a peacetime LCOM simulation, only a small portion of the total maintenance activity, particularly in the Munitions Maintenance Squadron, will not be simulated:

Mission Categories Primary/Alternate	Description
ACT/INT	Air Combat Tactics/Intercept
INT/IR	Intercept/In-Flight Refueling
ACT/IR	Air Combat Tactics/In-Flight Refueling
IAF	Intercept Alert Force
DEP/OTHER	Deployment/Unique Command Flight Missions
INST	Instrument Check.

With this approach, the operational missions are flexible for satisfying GCC requirements. The maintenance schedule is not affected, since it is dictated by aircraft configuration. Table 6 illustrates a typical European AFB peacetime daily schedule utilizing this approach for scheduling missions.

Operations Software - The peacetime operations data base contained the flying schedule and scheduled maintenance phase inspection schedule and supported a 72 UE TFW. The following criteria developed from the definition of data requirements, discussed in detail in Reference 14,

TABLE 4 AEROSPACE VEHICLE STATUS CODES

9–2720

CODE	DEFINITION	OLD CODE
FMC	FULL MISSION CAPABLE	OR
PMC	PARTIAL MISSION CAPABLE	NORM-F/NORS-F
NMC	NOT MISSION CAPABLE	TOTAL NORM-G AND NORS-G
UNMCB	UNSCHEDULED NOT MISSION CAPABLE BOTH (MAINTENANCE AND SUPPLY)	NORM-G (UNSCH) / NORS-G
SNMCB	SCHEDULED NOT MISSION CAPABLE BOTH (MAINTENANCE AND SUPPLY)	NORM-G (SCH) / NORS-G
UNMCM	UNSCHEDULED NOT MISSION CAPABLE MAINTENANCE	NORM-G (UNSCH)
SNMCM	SCHEDULED NOT MISSION CAPABLE MAINTENANCE	NORM-G (SCH)
NMCS	NOT MISSION CAPABLE SUPPLY	NORS-G
PMCB	PARTIALLY MISSION CAPABLE BOTH (MAINTENANCE AND SUPPLY)	NORM-F / NORS-F
PMCM	PARTIALLY MISSION CAPABLE MAINTENANCE	NORM-F
PMCS	PARTIALLY MISSION CAPABLE SUPPLY	NORS-F

NOTE: NEW CODES HAVE NOT BEEN INCORPORATED IN THE LCOM.
VARIABLE IDENTIFIERS SUCH AS NORS PER TABLE 3 HAVE BEEN USED.

TABLE 5 TYPICAL PEACETIME MISSIONS

9–2721

CATEGORY	MISSION TYPES	PERCENT	AIRCRAFT CONFIGURATION
ACT	AIR COMBAT TACTICS	59	B + 6C
DACT	DISSIMILAR ACT	2	B + 6C
AARD	AIR REFUELING DAY	5	B + 6C
DART	TOW TARGET – GUN	10	B + 6 H
ECMD	ELECTRONIC COUNTERMEASURES DAY	5	B + 2 + 6C
AARN	AIR REFUELING NIGHT	5	B + 6C
ECMI	ECM NIGHT	2	B + 2 + 6C
NNMI	NIGHT INTERCEPT	2	B + 2 + 6C
OTHER	EXAMPLES:	10	
	(1) INSTRUMENTS CHECK		(1) B + 6C
	(2) RED FLAG AND WSEP (CONUS)		(2) C + 1 + 4 + 6H
	(3) ALERT (EUROPEAN)		(3) B + 1 + 4 + 6H

were used during construction of the operational scenarios related to the flying programs depicted in Table 7. CONUS and European AFB operational factors indicated that a typical peacetime flying schedule involved a sortie rate of 0.8, while the lower and upper limits of 0.4 and 1.2 rates reflected decreased or increased demands in the peacetime environment (Table 7).

The operations software specified the number of spare aircraft, through-flights, washes, and phase inspections. In this study, the following conditions were applied: 65 percent of scheduled aircraft were through-flighted each day; airframes received a phase inspection every 50 hours; spare aircraft were based on 20 percent of first flight scheduled aircraft. Appendix B of Reference 15 summarizes the daily flying schedules used for the final LCOM simulations in this study. These flying schedules represented aircraft utilization rates of approximately 10, 20, and 30.

Maintenance Data

Operations data govern how the aircraft will be flown. Maintenance data describe how the aircraft will be maintained. The command doctrine governing maintenance procedures must be known in order to collect these data. Maintenance doctrine governs how and at what level, i.e., organizational, intermediate, or depot, specific types of maintenance are accomplished--which items are worked on, where and when the work is performed, and by whom it is accomplished and inspected. For this reason, the maintenance data incorporated in the LCOM data base are defined by class of data, type, and resource.

Classes of Maintenance Data - Two classes of maintenance data are usually defined to ensure compatibility with the input requirements of LCOM. These are scheduled and unscheduled maintenance. Scheduled maintenance deals with everyday scheduled tasks required to service and maintain the aircraft, e.g., preflight inspections. Phase maintenance is included in scheduled, but is performed on a periodic basis. Unscheduled maintenance consists of those corrective tasks, performed both on and off the aircraft, required as a result of hardware failures.

In terms of the model requirements, unscheduled maintenance demands the most definition. This is because the task types and resource requirements are dependent on the failure rates of the individual components. Scheduled and phase maintenance, on the other hand, can be anticipated and so treated differently, since the type and resource requirements can be scheduled in conjunction with flight operations.

Maintenance Types - For the fighter aircraft used in this study, the work unit code manual defines 12 aircraft and 11 engine Type Maintenance Codes. A code consists of an alpha character and is used to describe the maintenance performed. For example, Type Maintenance Code B designates unscheduled maintenance. In conjunction with the Type Maintenance Code is the Action Taken Code. This code consists of an

TABLE 6 SPECIFIC DAILY MISSION PARAMETERS

9–2725

PARAMETERS	MISSION TYPES					
	ACT/IR	ACT/INT	INT/IR	IAF	DEP	INST
APPROXIMATE % OF TOTAL SORTIES/DAY	5	72	7	8	6	2
MISSION PRIORITY (1 – HIGHEST)	2	3	2	1	1	4
FLIGHT SIZES MAXIMUM/MINIMUM AIRCRAFT	3/2	4/2	3/1	1/1	2/1	2/1
AVERAGE SORTIE LENGTH (HOURS)	1.5	1.0	2.3	1.4	1.3	1.5
(%) DAY/(%) NIGHT	100/0	100/0	0/100	50/50	100/0	100/0
CANCEL TIME (HOURS)	1.5	2	1.5	0.03	2	2
LEAD TIME (HOURS)	2	2	2	0.26	2	2
SPARE AIRCRAFT AVAILABILITY (% OF TOTAL AIRCRAFT SCHEDULED FOR FIRST FLIGHT/DAY)	20	20	20	50	20	20
PERCENT OF CANCEL DUE TO WEATHER LIMITATIONS	6	6	6	0	6	6
AIRCRAFT CONFIGURATION	B+6C	B+6C	B+6C	B+1+4+6H	B+6C	B+6C

TABLE 7 PROPOSED FLYING PROGRAM

9–2726

OPERATIONAL PARAMETER	UTILIZATION RATE=10	UTILIZATION RATE=20	UTILIZATION RATE=30
NUMBER OF U.E.	72	72	72
FLYING HOURS/MONTH	720	1440	2160
FLYING DAYS/WEEK	5	5	5
FLYING DAYS/MONTH	22	22	22
FLYING HOURS/DAY	32.73 = (720/22)	65.45 = (1440/22)	98.18 = (2160/22)
FLYING HOURS/SORTIE	1.14	1.14	1.14
SORTIES/DAY	23.7 = (32.73/ 1.14)	57.4 = (65.45/1.14)	86.1 = (98.18/1.14)
SORTIE RATE $\left(\frac{\text{SORTIES/DAY}}{\text{NO. OF U.E.}}\right)$	0.40	0.80	1.20

alpha or numeric character and identifies what work was done. For example, Action Taken Code R designates a remove and replace action whenever an item is removed and a like item installed. By using these codes, the sort of maintenance performed can be determined.

These codes tell nothing about the cause of an equipment malfunction or the manner in which the discrepancy was discovered. These are functions of the How Malfunctioned and When Discovered Codes. The How Malfunctioned Code consists of three numeric characters, and the When Discovered Code an alpha character. These two codes can be incorporated to identify when the item failed, e.g., inflight, no abort (Code D), and how the equipment failed, e.g., overheated (Code 900).

Consistent with the objective of limiting the model to essentials, the list of maintenance actions considered for LCOM simulation can often be reduced by combining minor and infrequent tasks. Those which logically can be combined with other major tasks, e.g., troubleshoot, and those using identical resources can be combined, thereby reducing the size of the data base. Tasks performed frequently, however, or those requiring considerable manpower and support equipment are potential sources of significant maintenance effort and should be treated separately.

Resources - In defining the maintenance resource data, the critical factors are (a) manning specialty, Air Force Specialty Code (AFSC), (b) crew size, (c) task time, (d) support equipment, and (e) parts.

The AFSC and crew size indicate the maintenance specialty and number of specialists required to accomplish the maintenance task. Task time defines the length of time support resources must be committed to ensure task completion. Support equipment resources identify significant pieces of support equipment required to accomplish the maintenance, and parts identify the parts required. People, support equipment, and parts may all be sources of aircraft constraint due to their non-availability. For this study, data were collected on the above items from a CONUS AFB and a European AFB.

Maintenance Concepts - Basic maintenance concepts of the USAF are presented in AFM-66-1, Maintenance Management (Reference 23). This technical manual describes a centralized management system of specialists/technicians with associated planning, scheduling, job control, material control, quality control, and deficiency and production analyses accomplished at the Chief of Maintenance level. The Chief of Maintenance is normally located at wing level. This office may also be at squadron level, depending on operational requirements. It is possible, for example, to have a wing of 72 UE aircraft at a single location, which is assumed for this peacetime study, with the Chief of Maintenance controlling the entire activity. If the wing deploys two ways, i.e., 48 UE aircraft at one base and 24 detached to another, the operational concept dictates a division of maintenance assets. Under either concept, the

Wing Chief of Maintenance will be responsible for supervising the entire maintenance effort and will have a maintenance staff at both locations.

Maintenance activities modeled in LCOM simulation studies follow current AFM 66-1 concepts. However, staff functions of the Chief of Maintenance are not in the actual simulation. The reasons for excluding these staff functions are, first, overhead spaces do not directly impact sortie accomplishment, and second, manning standards have been (or can be) more easily established for these staff elements using more conventional management techniques.

Cannibalization - Aircraft cannibalization is the maintenance practice of replacing a failed item on an aircraft being processed for a mission with an operational item from another aircraft that either is not scheduled for flight or is in a NORS condition. Cannibalization begins when the minimum number of aircraft required for a mission is greater than the number available. Air Force policy is to avoid cannibalization. Therefore, the process will be initiated only when spare parts are unavailable from supply, and a failed component cannot be repaired in time. Hence, this process will generate additional maintenance since several tasks are performed twice.

The number of cannibalizations per 100 sorties is an indication of how well the stock level in range and depth is able to meet the maintenance requirements of those aircraft assigned to an organization. Although no USAF standard has been set for this study's current operational fighter, 5 to 10 cannibalizations per 100 sorties would be considered an average value based on available data. For example, in October 1977 at the CONUS and European AFBs, there were 451 cannibalizations of which 143 were for engine systems. There were 121 aircraft cannibalizations at the CONUS AFB (not counting engines) involving 44 items. At the European AFB, there were 187 aircraft cannibalizations (not counting engines) involving 60 items.

Deferred Maintenance - Deferred maintenance occurs when aircraft are mission processing and the minimum required is greater than aircraft available. Deferred maintenance is initiated when spare parts are constrained, a failed component cannot be repaired in time for the mission, but that part is not required for successful accomplishment of the mission. A deferred maintenance concept defines maintenance tasks in the following groupings:

1. Flight essential
2. Mission essential
3. Deferrable to after flight
4. Deferrable to end of day
5. Deferrable to major inspection.

Reference 14 illustrates the minimum avionics equipment requirements for this study's current operational fighter to satisfy effectively GCC peacetime requirements on a daily basis. The list does not apply to Alert (also referred to as ZULU operations) nor to Operational Readiness Inspections (ORI)/TAC Evaluations. Since the LCOM deferred maintenance process does not check for a component's availability for a flight and other major aircraft failure items are related to the propulsion system, deferred maintenance for this fighter's peacetime missions is not a viable/significant concept to be considered for this study.

Maintenance Software - An existing data base for a fighter aircraft was modified. The major revisions were in terms of the maintenance organization structure, flight line activities, scheduled and unscheduled maintenance, repair/service times, spares pipeline times, and spares resources. The selected LRUs included in the data base were limited to those considered maintenance significant (at least one maintenance action in approximately 5000 sorties).

The maintenance software reflected current AFM 66-1 concepts. Reference 14 discusses the fighter aircraft organization structure, normal work centers, and Air Force Specialty Codes. Maintenance manpower shifts of 5 days per week based on demands or constrained levels and 2 days (weekend) with availability of minimum manpower per AFSC and work center were the criteria for maintenance software revisions. Appendix C of Reference 15 illustrates the various AFSCs and their shift allocations for the final LCOM simulations. During data base formulations the authors graphically depicted the maintenance environment using LCOM networks (Reference 14).

SENSITIVITY ANALYSIS

The preparatory efforts preceding the exercise of LCOM were largely relegated to the definition and acquisition of a data base that accurately represented the operations and maintenance environment of the weapon system being simulated and to the generation of the software to accomplish the initialization run. With the preparatory requirements accomplished as reported in Reference 14, the following activities were implemented to perform the sensitivity analysis: (a) processing initial LCOM simulations, (b) developing the experimental designs for the manpower and spares interaction and the manpower, spares, and support equipment interactions, and (c) performing the sensitivity analyses for the manpower and spares interaction and the manpower, spares, and support equipment interactions.

The results of each of the above activities are described in detail in Reference 15. Since the initial LCOM simulations, the experimental designs, and the statistical methodology for data analysis were critical to the approach for the final LCOM simulations, a brief discussion of each is provided in the following paragraphs.

Initial Maintenance Manpower Model Simulations

The initial LCOM runs established the definitions of the two levels of constrained spares and manpower. These results indicated that the best solution for decremented values was to define the maximum and minimum levels and to define at least one intermediate level so that trends effects could be established. Therefore, when the models of interaction were developed, these models would be representative for all possible combinations of interactions for a specified flying profile and maintenance concept. At various stages of the initial LCOM simulation process, the output data were examined for steady state and compliance with NORS criterion. This was done through visual examination of the output statistics, plotting of data, and application of statistical techniques (Reference 15).

Trends were established by these initial LCOM results. For example, a summary of aircraft parameters suggested a significant performance effect as a result of variations in the independent variables. Statistical tests of significance on these parameters indicate that, in all cases, the results were significant at the .05 level. The percent operational ready rate produced the most significant value in the comparison groups.

A comparison of the results also indicated that a significant interaction occurred between selected parameters. For example, it was observed that as spares or manpower was reduced, a significant increase in aircraft turnaround time was experienced. As a result, overall weapon system performance was decremented.

A demonstration simulation run of constrained avionics test stations was performed during the initial LCOM simulations. These significant results indicate that additional research effort should concentrate on support equipment impact and its relationship to manpower and spares utilizing the methodology developed by this study. Therefore, the Air Force provided additional funding to consider support equipment as a constrained resource for the full-scale simulation.

Experimental Designs For Sensitivity Analysis

Due to the contractual funding and scheduling and the desire to isolate the impact of ground support equipment interactions with manpower and spares resources, two full-scale LCOM simulations were accomplished. The first test structure involved the interactions of constrained manpower and spares resources with unconstrained support equipment resources. The second test structure involved the interactions of constrained manpower, spares, and support equipment resources.

Experimental Design for Manpower and Spares LCOM Simulations - The first test structure for the full-scale LCOM simulations was based on a four-factor design. These factors, or independent variables, were: (a) two maintenance concepts of with and without cannibalization,

(b) three aircraft utilization rates of 10, 20, and 30 flying hours per aircraft per month (equivalent to sortie rates of 0.4, 0.8, and 1.2 respectively), (c) three spare levels of baseline, average, and minimum, and (d) three manpower levels of baseline, average, and minimum. Baseline was defined as the resources required to have 95-100% sorties accomplished with an average NORS not to exceed 5%. The lower limits for manpower and spares were a minimum crew size for each AFSC and a lay-in spares quantity of one for each LRU. These minimum values were identical for the six test blocks. The average manning and average spares were selected at the midpoint between minimum and baseline with fractions rounded to the next higher spare or AFSC crew quantity.

The dependent variables identified in Columns A and B of Table 3 were examined for impact of the independent variables in combination. The listing in Table 3 used the numerical identifiers and nomenclature of LCOM II (Reference 11). Since support equipment was unconstrained in this experimental design, only dependent variable number 75, number of units demanded, in Table 3 was applicable for analysis in the support equipment category.

Experimental Design for Manpower, Spares, and Support Equipment LCOM Simulations - The second test structure for the full-scale simulations was based on a four-factor design involving manpower, spares, ground support equipment, and aircraft utilization rate. The maintenance concept selected for these simulations was "Concept 1 - Without Cannibalization". LCOM simulations were proposed to examine three levels of support equipment. Identification of factor levels is compatible with the first experimental design, Manpower and Spares Simulation.

Each test cell represents a unique combination of aircraft utilization rate, spares, support equipment, and manpower. This simulation plan yielded 81 simulation runs for final output data analyses. The minimum lay-in quantity for support equipment was set at one unit and a spare unit. Support equipment was selected for sensitivity analyses based on the criterion of high demands for its usage in aircraft maintenance associated with the missions simulated. The average quantity of support equipment was selected at the midpoint between minimum and baseline with fractions rounded to the next higher support equipment quantity. These levels are depicted in Appendix E of Reference 15.

Forty dependent variables (Column C, Table 3) were examined for impact of the independent variables in combination.

The initial LCOM runs were constrained in simulation run length to 91 days due to limitations in LCOM I which had an upper limit of 100 days for valid statistical computation without roundoff errors. Steady-state conditions, as statistically determined, were not achieved in all 91-day simulation runs (Reference 15). Therefore, the final simulation runs used LCOM II version and a simulation run length of 17 weeks (119 days) which was adequate to achieve a steady state.

Statistical Methodology for Data Analysis

Statistical methodology was established for the full-scale simulation runs and categorized into the following areas:

1. Steady State
2. Analysis of Variance.

This series of statistical tests provides a verification of the adequacy of the sample and an assessment of the sensitivity effects of the dependent/independent variables relationship. Detailed descriptions of each statistical analysis technique are provided in References 15 and 56.

APPROACH FOR MODELS OF MAINTENANCE RESOURCES INTERACTION

A computerized multiple regression program, BMD02R (Reference 57), was used to assess the impact of the independent variables upon the selected LCOM output dependent variables. This program was selected for its flexibility in addressing the data bank to develop the maintenance resource interaction models. Multiple regression equations express the statistical relationship between each of the dependent variables and the independent variables -- spares, manpower, support equipment, and utilization rate (References 16 and 58).

The statistical by-products of the regression technique provide indices for analyses throughout the stages of regression technique application. Interpretation of findings were based on an examination of the following: (a) Matrix of Correlation Coefficients provided information on the results of bivariate correlations, (b) Matrix of Partial-Correlation Coefficients provided information on degree of correlation of remaining variables following entry of an independent variable into the regression model, (c) Regression Sum of Variance identified the proportion of variance attributed to a particular independent variable, and (d) Standard Error of Estimate described the deviation units of the residual from the regression line.

The BMD02R computes a sequence of multiple regression equations in a stepwise manner. The stepwise procedure controls the entry of an independent variable into the regression model by systematically selecting that variable which yields the highest correlation with the dependent variable. Each succeeding computed partial correlation of the remaining variables represents that part of the variation in the dependent variable not explained by a predictor (independent) variable already in the model. In this manner, the end result is a multiple regression equation that defines the individual contributions of the variables and their combined contributions as measured by the regression sum of squares.

The approach to applying the BMD02R was to develop regression models that addressed themselves specifically to each experimental design. Additionally, the sets of data for each utilization rate (UR) were segregated for the analysis, following which the three sets of data were pooled. This method of model development resulted in a set of four regression equations for each dependent variable, specifically UR 10, UR 20, UR 30, and all URs combined for each experimental design. Since Reference 15 showed findings that indicated sensitivity effects of resources upon all dependent variables used in the study, regression model development was pursued on all variables (Reference 16).

III. RESULTS

SUMMARY

The development of models of interaction was accomplished by a two-stage analysis. In the first stage, the observed values of the dependent variables associated with factorial combinations of spares, manpower, support equipment, utilization rate, and first-order interactions (SxM, SxSE, SxUR, MxSE, MxUR and SExUR) were analyzed in a General Linear Model (GLM) program, to extract from the original dependent variables some subset which showed sensitivity to variations in those resources. A detailed description of the sensitivity analyses for manpower x spares without cannibalization, manpower x spares with cannibalization, and manpower x spares x support equipment without cannibalization are contained in Reference 15. The net result of the first stage of the analysis indicated that all variables were sensitive to variations in at least one of the resources. Such findings were significant at the .05 level of probability. As a consequence of these results, all dependent variables were retained for development of models of interaction. This was accomplished in the second stage of the analysis. A summary of findings for the models of interaction is provided in Tables 8, 9, and 10 for the three data sets. Column (A) identifies the number of dependent variables examined in each category. Columns (B) through (F) for Tables 8 and 9 and Columns (B) through (G) for Table 10 report the average percentage contribution made by the independent variables in the regression models. The higher the percentage contribution, the greater the predictive utility of that independent variable in providing estimated values of a dependent variable. The last column in each table reports the total contribution of all terms in an estimating equation. To illustrate, an R^2 of 85% represents the percentage of variation in the dependent variable that is accounted for in an estimating equation. Since these tables summarize the results by averaging across equations for a dependent variable, actual values should be examined to determine a specific dependent/independent variable relationship. These are available in Reference 16. Using R^2 values as a criterion, the equations examining spares, manpower, and utilization rate (Tables 8 and 9) were better than the equations which examined spares, manpower, support equipment, and utilization rate (Table 10).

MANPOWER AND SPARES ANALYSES

The lower and upper limits of the independent variables were:

Spares	Manpower	UR
411 to 444	339 to 719	10
411 to 636	339 to 828	20
411 to 735	339 to 1276	30
411 to 735	339 to 1276	10 to 30

TABLE 8 AVERAGE PERCENT CONTRIBUTION OF INDEPENDENT VARIABLES IN THE REGRESSION MODELS- SPARES x MANPOWER x UTILIZAT[illegible]E WITHOUT CANNIBALIZATION

(A) CATEGORY	(B) L / Q	(C) MANPOWER	(D) SPARES	(E) UR	(F) 2-FACTOR INTERACTIONS	(G) TOTAL CONTRIBUTION (R2)
OPERATIONS (2)	L	61.39% - 65.81%	0.13% - 3.31%	12.67% - 37.16%	20.89%	91.73% - 96.78%
	Q	20.62% - 27.00%	0.10% - 0.13%	-		
AIRCRAFT (11)	L	12.81% - 75.42%	0.10% - 84.28%	0.87% - 33.29%	0.23% - 59.55%	78.93% - 97.80%
	Q	5.37% - 53.76%	0.05% - 4.52%	0.61% - 11.39%		
MANPOWER (8)	L	4.90% - 79.60%	0.22% - 5.45%	1.33% - 21.33%	5.22% - 37.86%	64.37% - 97.90%
	Q	13.52% - 94.56%	0.19% - 22.30%	0.81% - 9.56%		
SHOP REPAIR (6)	L	7.53% - 67.00%	5.22% - 57.11%	3.11% - 4.32%	3.33% - 19.43%	28.35% - 93.85%
	Q	2.74% - 22.15%	31.26% - 91.03%	2.28% - 16.52%		
SPARES SUPPLY (6)	L	11.99% - 67.50%	0.55% - 84.38%	4.21% - 25.13%	28.58% - 49.89%	69.47% - 93.92%
	Q	5.06% - 21.83%	0.20% - 80.14%	4.21% - 25.13%		
SUPPORT EQUIPMENT (1)	L	68.29% - 73.37%	1.09% - 1.10%	1.75% - 2.25%	55.44%	86.10% - 86.57%
	Q	15.81% - 22.52%	9.04% - 9.44%	5.28% - 5.32%		
COLUMN SUMMARIES	L	4.90% - 79.60%	0.10% - 84.38%	0.87% - 37.16%	0.23% - 59.55%	28.35% - 97.90%
	Q	2.74% - 94.56%	0.05% - 91.03%	0.61% - 16.52%		

L = LINEAR COMPONENT
Q = QUADRATIC COMPONENT

NOTE: THE VALUES WERE COMPUTED AS FOLLOWS: FOR EACH SUBSET OF EQUATIONS (E.G., DEPENDENT VARIABLE 3 HAD 4 EQUATIONS), THE AVERAGE PERCENT OF CONTRIBUTION WAS COMPUTED FOR EACH EFFECT. WITHIN EACH CATEGORY OF VARIABLES (E.G., OPERATIONS), THE LOWEST AND HIGHEST AVERAGES WERE REPORTED IN COLUMN (C) THROUGH (F).

TABLE 9 AVERAGE PERCENT CONTRIBUTION OF INDEPENDENT VARIABLES IN THE REGRESSION MODELS-SPARES x MANPOWER x UTILIZATION RATE WITH CANNIBALIZATION

(A) CATEGORY	(B) L Q	(C) MANPOWER	(D) SPARES	(E) UR	(F) 2-FACTOR INTERACTIONS	(G) TOTAL CONTRIBUTION (R2)
OPERATIONS (2)	L	62.83% - 65.67%	1.11% - 3.25%	13.41% - 37.57%	NOT EVALUATED	95.25% - 96.77%
	Q	20.55% - 26.89%	0.10% - 0.13%	-		
AIRCRAFT (2)	L	71.93% - 72.09%	0.23% - 4.30%	2.74% - 4.04%	NOT EVALUATED	94.39% - 97.73%
	Q	18.02% - 24.94%	0.15%	-		
MANPOWER (2)	L	70.20% - 74.31%	3.93%	0.75% - 3.87%	NOT EVALUATED	86.82% - 94.15%
	Q	16.44% - 18.85%	-	0.82%		
SHOP REPAIR (1)	L	66.65%	5.12%	3.13%	NOT EVALUATED	93.66%
	Q	0.20%	22.35%	-		
SPARES SUPPLY (2)	L	28.02% - 66.61%	4.90% - 14.57%	3.16%	NOT EVALUATED	48.32% - 93.44%
	Q	13.57% - 22.17%	0.82% - 10.34%	-		
RANGE OF AVERAGE VALUES	L	62.83% - 74.31%	0.23% - 14.57%	0.75% - 37.57%		48.32% - 97.73%
	Q	0.20% - 26.89%	0.10% - 22.35%	0.82%		

L = LINEAR COMPONENT
Q = QUADRATIC COMPONENT

NOTE: THE VALUES WERE COMPUTED AS FOLLOWS: FOR EACH SUBSET OF EQUATIONS (E.G., DEPENDENT VARIABLE 3 HAD 4 EQUATIONS), THE AVERAGE PERCENT OF CONTRIBUTION WAS COMPUTED FOR EACH EFFECT. WITHIN EACH CATEGORY OF VARIABLES (E.G., OPERATIONS), THE LOWEST AND HIGHEST AVERAGES WERE REPORTED IN COLUMN (C) THROUGH (F).

TABLE 10 AVERAGE PERCENT CONTRIBUTION OF INDEPENDENT VARIABLES IN THE REGRESSION MODELS-SPARES x MANPOWER x SUPPORT EQUIPMENT x UTILIZATION RATE

(A) CATEGORY	(B) L Q	(C) MANPOWER	(D) SPARES	(E) SUPPORT EQUIPMENT	(F) UR	(G) 2-FACTOR INTERACTIONS	(H) TOTAL CONTRIBUTION (R2)
OPERATIONS (2)	L	6.88% - 24.82%	1.41%	31.81% - 43.41%	10.90% - 24.65%	23.18%	65.38% - 72.72%
	Q	5.73% - 17.47%		0.00% - 24.91%	15.88%		
AIRCRAFT (11)	L	1.31% - 74.05%	0.22% - 58.75%	0.55% - 45.17%	0.56% - 14.93%	17.22% - 29.79%	55.88% - 95.05%
	Q	3.24% - 26.70%	0.71% - 7.21%	1.00% - 7.88%	1.03% - 17.40%		
MANPOWER (8)	L	0.87% - 84.70%	0.21% - 2.67%	0.70% - 48.64%	0.55% - 6.76%	5.26% - 25.98%	58.69% - 97.03%
	Q	2.94% - 19.13%	0.16% - 2.32%	1.69% - 20.52%	0.45% - 13.44%		
SHOP REPAIR (6)	L	4.11% - 24.65%	22.38% - 48.82%	1.80% - 32.74%	2.16% - 12.42%	11.02% - 20.40%	15.85% - 66.28%
	Q	3.80% - 8.39%	12.19% - 37.06%	2.31% - 7.96%	-		
SPARES SUPPLY (6)	L	1.53% - 23.11%	1.54% - 63.75%	3.86% - 43.57%	0.44% - 17.22%	6.19% - 25.48%	57.99% - 84.17%
	Q	2.35% - 69.64%	5.51% - 70.53%	1.63% - 19.31%	0.31% - 2.53%		
SUPPORT EQUIPMENT (6)	L	5.04% - 68.66%	1.71% - 9.70%	5.04% - 68.66%	1.21% - 5.31%	7.12% - 27.45%	50.55% - 77.56%
	Q	6.54% - 19.15%	2.19% - 3.61%	2.97% - 3.37%	1.17% - 27.78%		
RANGE OF AVERAGE VALUES	L	0.87% - 84.70%	0.21% - 63.75%	0.55% - 68.66%	0.44% - 24.65%	5.26% - 29.79%	15.85% - 97.03%
	Q	2.35% - 69.64%	0.45% - 70.53%	1.00% - 24.91%	0.31% - 27.78%		

L = LINEAR COMPONENT
Q = QUADRATIC COMPONENT

NOTE: THE VALUES WERE COMPUTED AS FOLLOWS: FOR EACH SUBSET OF EQUATIONS (E.G., DEPENDENT VARIABLE 3 HAD 4 EQUATIONS), THE AVERAGE PERCENT OF CONTRIBUTION WAS COMPUTED FOR EACH EFFECT. WITHIN EACH CATEGORY OF VARIABLES (E.G., OPERATIONS), THE LOWEST AND HIGHEST AVERAGES WERE REPORTED IN COLUMN (C) THROUGH (G).

The summary values of each simulation run were used. This resulted in nine data points (three levels of manpower x three levels of spares) for each utilization rate and 27 (three levels of manpower x three levels of spare x three levels of utilization rate) when all simulations were pooled. The regression equations computed for each dependent variable considered utilization rate as a constant--10, 20, or 30--and then as a predictor variable.

Models of Interaction for Maintenance Concept Without Cannibalization

Thirty-four dependent variables were examined as reported in Reference 16. These are identified in Table 3. Type 1 equations assessed the contribution of the linear and quadratic components of the main effects--spares, $spares^2$, manpower, $manpower^2$, utilization rate, and utilization $rate^2$. From this list of 34, a subset of 22 was selected for Type 2 equations which assessed the combined contributions of the aforementioned components and the interactions of the main effects, spares x manpower, spares x utilization rate, and manpower x utilization rate. This permitted a comparative examination of the predictive strength of each type of equation. Since equations with interaction terms can be more complex than without, it was desirable to justify the use of a more complex equation if the findings showed a clear gain in predictive strength over Type 1 equations.

The results of the Type 1 equations indicated that manpower played the dominant role in most regressions with accountable regression sum of squares ranging from 0.30% to 98.83% for the linear and 0.23% to 98.58% for the quadratic components, with respective average contributions of 50.88% and 20.24%. Spares contributed to the predictive power of the model in the range of 0.08% to 84.38% for the linear and 0.05% to 91.03% for the quadratic components, with the average contribution higher for the quadratic component, 30.79% as opposed to 18.27%, although frequency of occurrence was lower by a factor of 2. An overview of these results is contained in Table 11.

A comparative evaluation of Type 1 and Type 2 equations is provided in Table 12. These values were derived by averaging across regression equations for a dependent variable (UR10, 20, 30, and UR combined). The results indicated that gains in predictive strength of the regression models, as measured by R^2, can be achieved in some cases by including interaction terms in the equations. The set of variables in Table 12 was impacted by interaction of main effects ranging from 0.06% to 79.53%. Regression equations may be reviewed individually in Reference 16 for large components of interaction and associated large R^2 gains. For example, although Table 12 shows that the average predictive strength of Type 1 equation for dependent variable 8 was superior to Type 2, a review of an actual equation from this set, i.e., where utilization rate was examined as a predictor variable, showed the following:

TABLE 11 SPARES x MANPOWER x UTILIZATION RATE WITHOUT CANNIBALIZATION TYPE 1 EQUATIONS- LINEAR AND QUADRATIC COMPONENTS OF MAIN EFFECTS

No. of dependent variables examined:	34
Spares contribution in the regression models:	34 out of 34 - Linear Component with an average contribution of 18.27%
	16 out of 34 - Quadratic Component with an average contribution of 30.79%
Manpower contribution in the regression models:	31 out of 34 - Linear Component with an average contribution of 50.88%
	32 out of 34 - Quadratic Component with an average contribution of 20.24%
Utilization Rate contribution in the regression models:	26 out of 34 - Linear Component with an average contribution of 10.40%
	12 out of 34 - Quadratic Component with an average contribution of 3.11%

TABLE 12 SPARES x MANPOWER x UTILIZATION RATE WITHOUT CANNIBALIZATION COMPARISON OF TYPE 1 AND TYPE 2 EQUATIONS (WITHOUT AND WITH INTERACTION TERMS)

No. of dependent variables examined - 22.

	Average Predictive Strength as Measured by R^2		Gain
Dependent Variable	Type 1 Equation Without Interaction Terms	Type 2 Equation With Interaction Terms	Type 2 Minus Type 1
8	95.45%	91.73%	-
15	94.46	92.55	-
16	89.12	79.83	-
17	88.93	88.03	-
18	80.83	87.98	+
19	93.11	92.98	-
20	97.69	97.80	+
21	87.47	91.90	+
23	94.05	92.51	-
28	64.37	69.35	+
29	93.49	92.12	-
33	94.21	92.93	-
38	81.39	93.94	+
40	89.81	91.37	+
47	67.35	68.50	+
48	61.15	67.27	+
49	61.15	67.27	+
55	89.11	88.64	-
56	79.85	87.26	+
57	93.92	92.19	-
61	89.11	88.63	-
75	86.57	86.10	-

Without first-order interaction terms

Estimated V8 = -19.8687 + 0.2806 (Manpower) +0.0540 (Spares) - 2.2855 (Utilization Rate) - 0.0001 ($Manpower^2$)

R^2 = 87.93%

Standard Error of Estimate = 11.57%

With first-order interaction terms

Estimated V8 = 31.8666 + 0.2276 (Manpower) -4.2860 (Utilization Rate) - 0.0002 ($Manpower^2$) $+0.8 \times 10^{-4}$ (Manpower x Spares) + 0.0040 (Manpower x Utilization Rate)

R^2 = 93.53%

Standard Error of Estimate = 8.67%

In this example the equation including the first-order interactions has better predictive power, where the R^2 value indicates that 93.53% of the variation in V8, Percent Sortie Accomplished, can be explained by the five main and interaction effects in the equation. The standard error of estimate is also smaller, 8.67% vs. 11.57% (i.e., two-thirds of the residuals are expected to be within ± 8.67 units from the regression line). Figures 3 and 4 are graphic approximations of the relationship of manpower and spares to four dependent variables.

In Figure 3, the Y axes represent four dependent variables that were examined. The X axes represent the manpower range from 339 to 828, within which the low, intermediate, and high levels were selected as simulation parameters. In the graph for percent sorties accomplished, a similarity in trend is evident. For the baseline spares and average spares conditions, it is expected that with manpower lay-in of 573, close to 100% sorties accomplished can be achieved. With minimum spares, incremental gains in manpower beyond 573 can result in an increase in percent sorties accomplished. In the graph for percent operationally ready, improvement in that rate can be achieved by increasing manpower. However, at a manpower level of 573, the unit change in manpower produces a diminishing gain in percent operationally ready rate. In the third graph percent not operationally ready is adversely affected more by spares resources than manpower, while average aircraft post-sortie time is adversely affected more by manpower than spares. Figure 4 presents the same material as Figure 3 except that the X axes represent the spares range from 411 to 636, and each graphed line represents a particular manpower level. While the visual perspective is different, the interpretations of the graphed lines are the same.

Models of Interaction for Maintenance Concept With Cannibalization

Two sets of data representing without and with cannibalization conditions were examined first by applying the General Linear Model (GLM) program to determine whether there were significant differences due to

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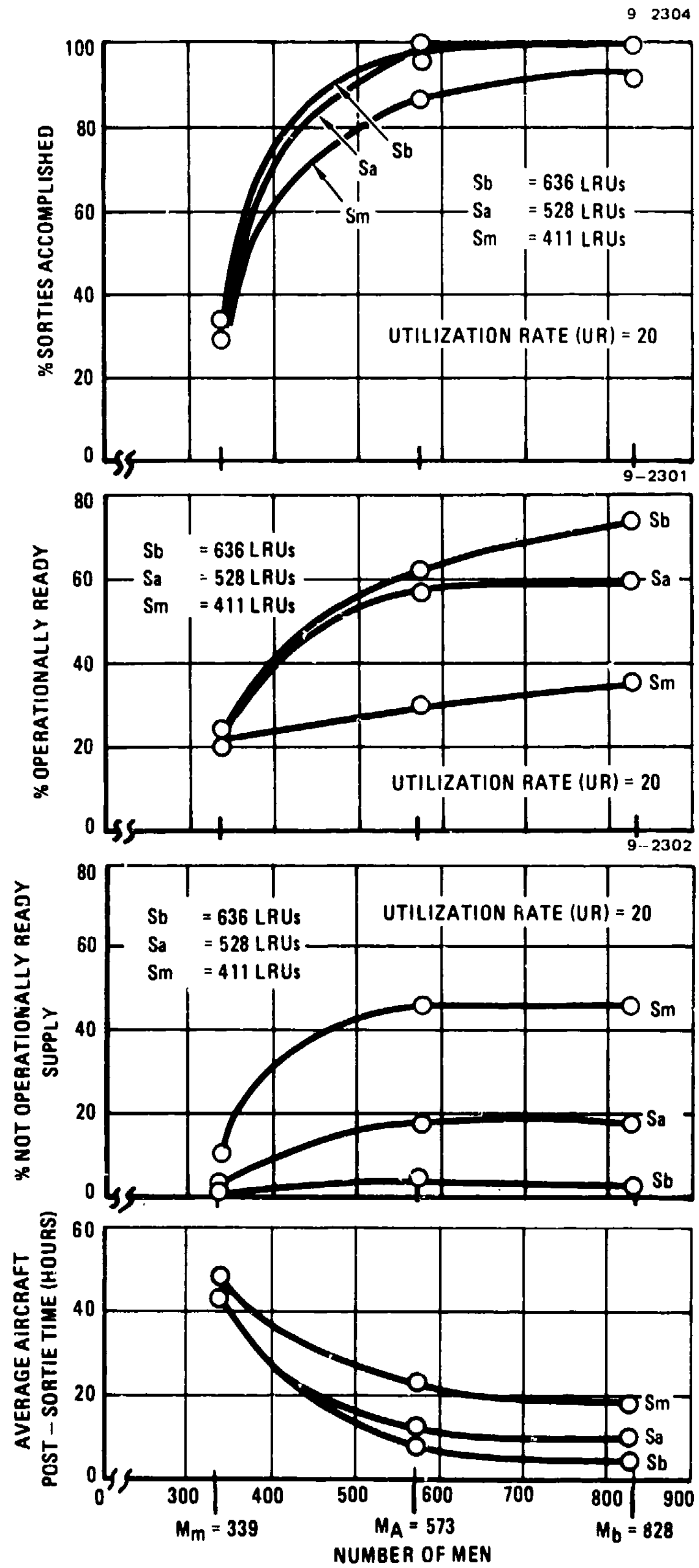

FIGURE 3 PERFORMANCE PARAMETERS VERSUS DIRECT MANPOWER (UR = 20)

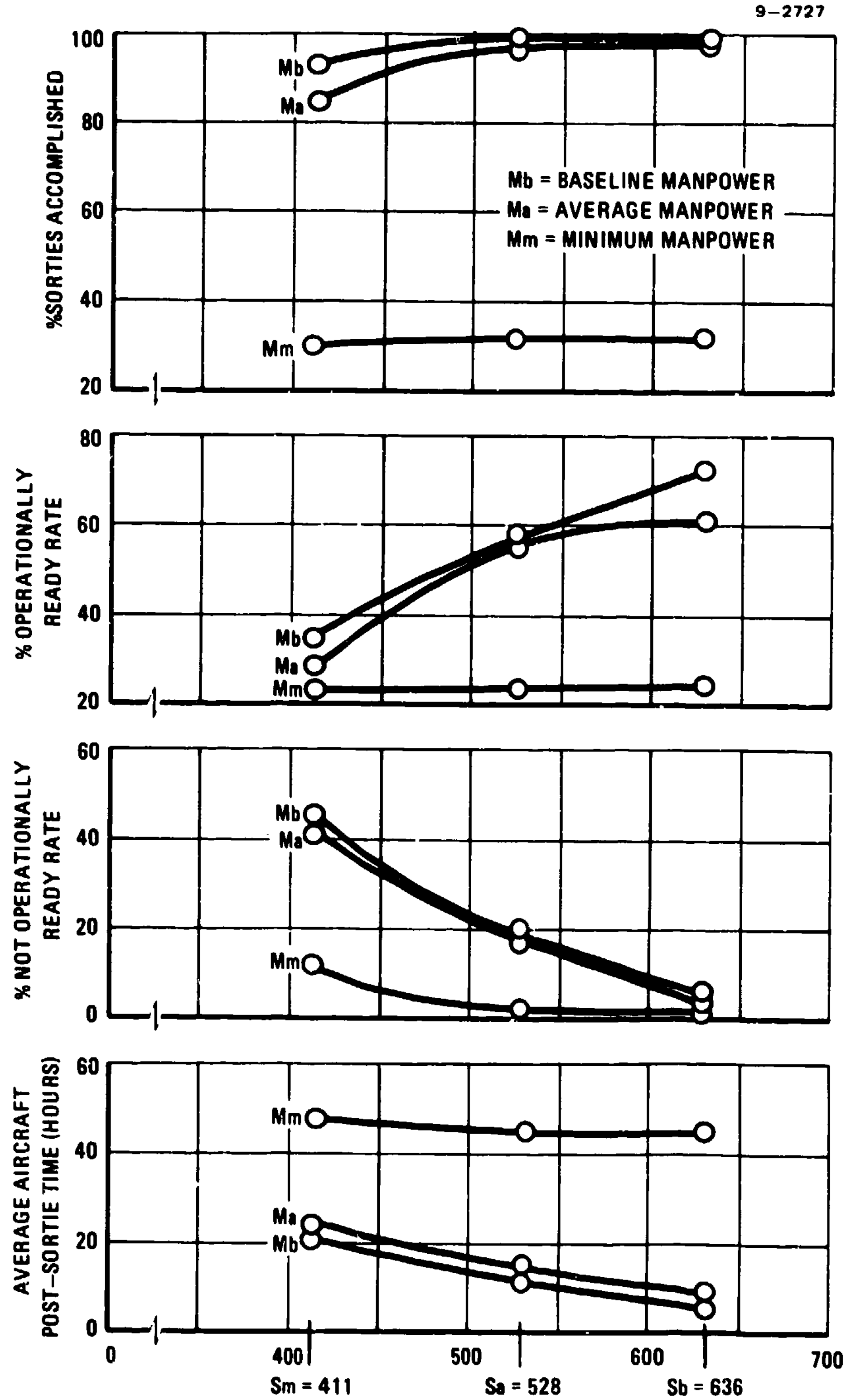

FIGURE 4 PERFORMANCE PARAMETERS VS SPARES SUPPLY (UR = 20)

the maintenance concept. The same 34 dependent variables used in the preceding analysis plus variable 62, were evaluated. Nine of the 35 indicated that the effects of maintenance concept were significant at the .05 level. These were V3, V8, V20, V24, V33, V40, V44, V57, and V62. Type 1 equations were derived for these nine variables to examine the linear and quadratic components of the main effects. An examination of the results as summarized in Table 13 indicated that the partitioning of the regression sums of square and the predictive strength, R^2, were very similar for comparative pairs of equations. From a practical standpoint, therefore, a separate series of equations for cannibalization concept was not particularly useful.

MANPOWER, SPARES, AND SUPPORT EQUIPMENT ANALYSES

The lower and upper limits of the independent variables were:

Spares	Manpower	Support Equipment	UR
411 to 444	354 to 779	275 to 291	10
411 to 636	354 to 972	275 to 318	20
411 to 735	354 to 1578	275 to 499	30
411 to 735	354 to 1578	275 to 499	10 to 30

As in the manpower and spares analyses, the summary values of each simulation run were used. This yielded 27 data points for deriving equations for each of the utilization rates, following which the data were pooled and utilization rate evaluated as a predictor variable. The manpower x spares x support equipment simulations considered one maintenance concept only - without cannibalization.

Models of Interaction

Thirty-nine dependent variables were examined. These are identified in Table 3. Type 1 equations assessed the contribution of the linear and quadratic components of the main effects--spares, spares^2, manpower, manpower^2, support equipment, support equipment^2, utilization rate, and utilization rate^2. From this list of 39, a subset of 22 was selected for Type 2 equations. These equations assessed the combined contributions of the aforementioned components and the interactions of the main effects, spares x manpower, spares x support equipment, spares x utilization rate, manpower x support equipment, manpower x utilization rate, and support equipment x utilization rate. This permitted a comparative examination of the predictive strength of each type of equation. Since equations with interaction terms can be more complex than without, it was desirable to justify the use of a more complex equation if the findings showed a clear gain in predictive strength over Type 1 equations. A summary of the results for Type 1 equations is presented in Table 14. The results indicated that manpower weight was much higher in the first analysis, manpower x spares x utilization rate, where an average 71.12% of the regression sum of squares (linear and quadratic components combined) was associated with manpower as compared to 29.43%

TABLE 13 SPARES x MANPOWER x UTILIZATION RATE COMPARISON OF TYPE 1 EQUATIONS FOR MAINTENANCE CONCEPT WITHOUT (W/O) AND WITH (W) CANNIBALIZATION

		S	S2	M	M2	U	U2	R2
V3	W/O	1.04	0.10	65.81	27.00	12.67	-	96.78%
	W	1.11	0.10	65.67	26.89	13.41	-	96.77
V8	W/O	3.31	0.13	62.72	20.93	37.16	-	95.45
	W	3.25	0.13	62.83	20.53	37.57	-	95.25
V20	W/O	0.26	-	71.86	24.88	3.04	-	97.69
	W	0.23	-	71.93	24.94	2.74	-	97.73
V24	W/O	4.30	0.10	72.14	18.04	4.13	-	94.46
	W	4.30	0.15	72.09	18.02	4.04	-	94.39
V33	W/O	3.95	-	70.23	18.85	3.91	0.81	94.21
	W	3.93	-	70.20	18.85	3.87	0.82	94.15
V40	W/O	0.65	0.92	76.40	16.05	2.38	0.89	89.81
	W	-	-	74.31	16.44	0.75	-	86.82
V44	W/O	5.22	-	67.00	22.15	3.11	-	93.85
	W	5.12	0.20	66.65	22.35	3.13	-	93.66
V57	W/O	5.07	-	67.50	21.83	3.14	-	93.92
	W	4.90	0.82	66.61	22.17	3.16	-	93.44
v62	W/O	Not Applicable						
	W	14.57	10.34	28.02	13.57	-	-	48.32

TABLE 14 SPARES x MANPOWER x SUPPORT EQUIPMENT x UTILIZATION TYPE 1 EQUATIONS – LINEAR AND QUADRATIC COMPONENTS OF MAIN EFFECTS

No. of dependent variables examined:	39
Spares contribution in the regression models:	30 out of 39 – Linear Component with an average contribution of 16.23%
	14 out of 39 – Quadratic Component with an average contribution of 22.31%
Manpower contribution in the regression models:	38 out of 39 – Linear Component with an average contribution of 22.29%
	37 out of 39 – Quadratic Component with an average contribution of 7.14%
Support Equipment contribution in the regression models:	30 out of 39 – Linear Component with an average contribution of 24.23%
	9 out of 39 – Quadratic Component with an average contribution of 10.19%
Utilization Rate contribution in the regression models:	28 out of 39 – Linear Component with an average contribution of 4.57%
	24 out of 39 – Quadratic Component with an average contribution of 4.70%

for this analysis. The contribution of spares in these models was somewhat less than in the first analysis, 38.54% as opposed to the previous 49.03%. With support equipment effects, the variations in the dependent variable because of support equipment variations approximated the magnitude that manpower exerted in the models, 34.42% vs. 29.43%. Spares had the highest predictive utility, support equipment was second, and manpower last. Categorically, the relationship between two variables--spares and manpower analysis--was better defined than the relationship among three variables--spares, manpower, and support equipment analysis.

Type 2 equations were derived for a subset of 26 variables to determine whether the predictive strength of the models could be enhanced by including interaction terms in the equation. A comparative evaluation of Type 1 and Type 2 equations is provided in Table 15. These values were derived by averaging across regression equations for a dependent variable (UR10, 20, 30, and all URS combined). The results indicate that gains in predictive strength of the regression models, as measured by R^2, can be achieved in a substantial number of cases by including interaction terms in the equations. The set of variables in Table 15 was impacted by interaction of main effects ranging from 0.01% to 58.24%. Regression equations may be reviewed individually in Reference 16 for large components of interaction and associated large R^2 gains. As an illustration of comparative pairs of equation, V18, Percent in NORS, is cited:

<u>Without first-order interaction terms</u>

$$\begin{aligned}\text{Estimated V18} = {} & -10.0547 + 0.0375\ (\text{Manpower}) \\ & -0.0854\ (\text{Spares}) + 0.0735\ (\text{Support Equipment}) \\ & +2.3044\ (\text{Utilization Rate}) - 0.01 \times 10^{-3} \\ & (\text{Manpower}^2)\ -0.0503\ (\text{Utilization Rate}^2)\end{aligned}$$

$R^2 = 57.36\%$

Standard Error of Estimate = 9.27%

<u>With first-order interaction terms</u>

$$\begin{aligned}\text{Estimated V18} = {} & -58.3784 + 1.2786\ (\text{Utilization Rate}) \\ & +0.0436\ (\text{Manpower}) + 0.2617\ (\text{Support} \\ & \text{Equipment}) - 0.0443\ (\text{Utilization Rate}^2) \\ & -0.2 \times 10^{-4}\ (\text{Manpower}^2) + 0.0001\ (\text{Spares}^2) \\ & +0.0009\ (\text{Utilization Rate} \times \text{Manpower}) \\ & -0.7 \times 10^{-4}\ (\text{Manpower} \times \text{Spares}) \\ & +0.6 \times 10^{-4}\ (\text{Manpower} \times \text{Support Equipment}) \\ & -0.0004\ (\text{Spares} \times \text{Support Equipment})\end{aligned}$$

$R^2 = 69.03\%$

Standard Error of Estimate = 8.12%

A gain of 11.67% in predictive strength can be realized by using the estimating equation with first-order interaction terms, with an average decrease in standard error of estimate of 1.15%.

TABLE 15 SPARES x MANPOWER x SUPPORT EQUIPMENT x UTILIZATION RATE COMPARISON OF TYPE 1 AND TYPE 2 EQUATIONS (WITHOUT AND WITH INTERACTION TERMS)

No. of dependent variables examined - 26.

Dependent Variable	Average Predictive Strength as Measured by R2: Type 1 Equation Without Interaction Terms	Type 2 Equation With Interaction Terms	Gain: Type 2 Minus Type 1
8	67.16%	72.72%	+
15	69.83	74.98	+
16	61.50	68.04	+
17	55.88	63.73	+
18	65.91	73.21	+
19	67.00	78.37	+
20	63.93	71.09	+
21	59.67	66.45	+
23	68.43	74.87	+
28	59.64	62.90	+
29	68.09	74.69	+
33	58.69	69.90	+
38	96.41	97.03	+
40	66.52	67.18	+
47	50.93	52.62	+
48	58.07	60.28	+
49	58.07	60.28	+
55	83.36	94.17	+
56	66.13	76.25	+
57	69.05	75.56	+
61	81.75	83.25	+
71	57.82	63.56	+
72	52.55	58.99	+
74	56.37	50.55	-
75	69.00	76.34	+
79	76.62	77.56	+

IV. CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

As the complexity of weapon systems increases, the manpower/systems interaction becomes more difficult to evaluate. Paper-and-pencil surveys are ineffective for assessing the effects of serial and parallel task events, or for determining task distribution and probability effects. Dynamic (man-in-the-loop) simulation and/or flight testing under operational conditions is expensive and, sometimes, restrictive in terms of objectives that can be satisfied. Hence, some technique, more sophisticated than paper-and-pencil but less expensive and more timely than dynamic simulation or flight testing, is needed to give equipment designers early quantitative data on maintainer workload capabilities. Computer-based models such as LCOM will fill this void. Prior effort has identified the advantages and disadvantages of computer-based models as well as other techniques (Reference 14). The specific benefits provided by LCOM and the regression models developed by this research effort are:

1. Answer "what-if" questions.

2. Eliminate total restudy.

3. Identify and justify "spare" capacity of manpower, spares, or support equipment resources.

4. Determine existing capability.

At the present time, five major human resources technologies are experienced independently at various discrete times of an Air Force weapon systems development cycle. These technologies are (a) Logistics Composite Model (LCOM), (b) Instructional System Development (ISD), (c) Job Guide Development (JGD), (d) System Ownership Cost (SOC), and (e) human resources in design trade-offs. Although there has been a recognition of similarities in activities and data requirements among these five technologies, the initial activities of the LCOM can have a significant impact on the other human resources technologies. For example, the impact of tasks versus skills on mission effectiveness, sortie effectiveness, operationally ready rate, aircraft turnaround times, and accomplished sortie rate per day can be investigated with the methodology developed by this study. Since some tasks will not have an impact on aircraft measures, such as sortie effectiveness, LCOM simulations can determine which spares and AFSCs are critical for future application of other human resources technologies. Figures 5 and 6 illustrate results depicting significant AFSCs and high demand spare units for this study.

The maintenance resources interaction models developed by this study provide a technique for (a) forecasting numbers of people, by occupational classification and skill, who will be required to operate

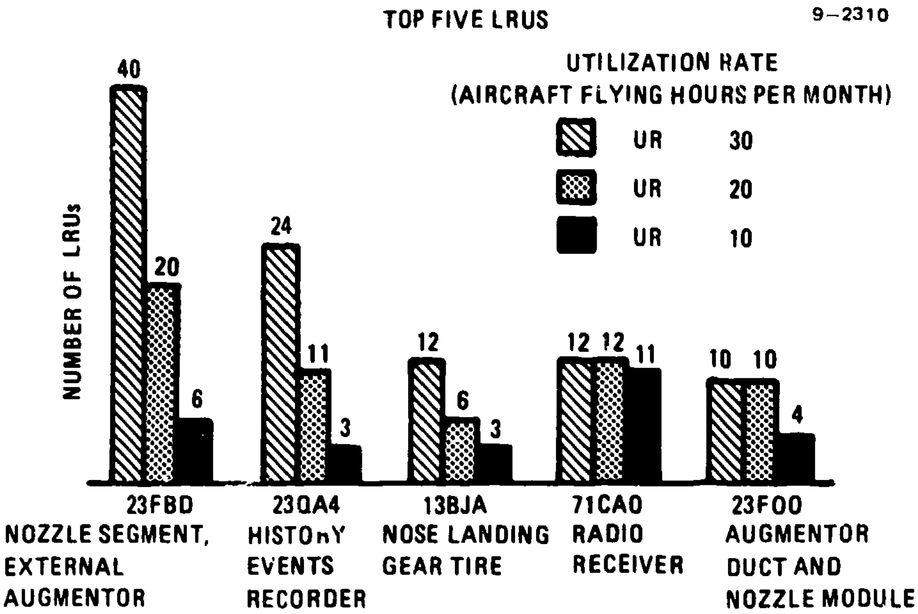

FIGURE 5 SPARES HISTOGRAM

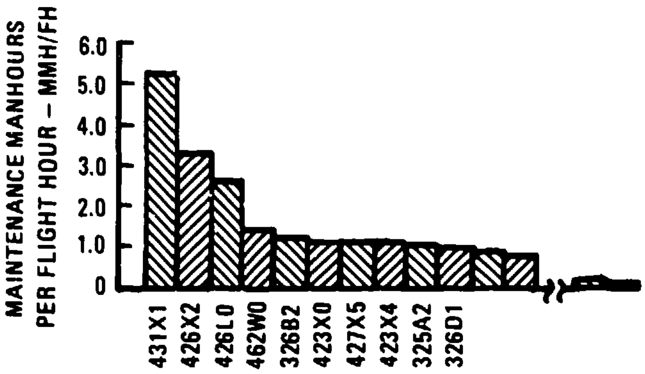

FIGURE 6 MANPOWER HISTOGRAM

or maintain a new or operational system, (b) forecasting manpower availability for any given time-series, considering the effects of major factors such as personnel policies, trends in entry-skill levels, training and human resource utilization, (c) maintaining a current interface of knowledge in human resources technologies application, (d) conducting feasibility studies for integrating exceptional features of multiple techniques to ultimately satisfy the objectives of human resources technologies, and (e) reducing the existing gap between human resources data and methods for providing the user with the data.

The developed interaction models can be used to assess the impacts of the interaction effects of resources on weapon system usage/design. These impacts can be used to guide system conceptual studies, to pinpoint promising configurations, to optimize the baseline configuration, and to identify the economic payoff of the optimized configuration. Translating field experience data into good design guidelines for reduced costs of ownership is extremely important in meeting life cycle cost objectives. Analysis and evaluation of actual data provide the most effective approach to identifying equipment exhibiting poor reliability and requiring high maintenance manhours. The results of this research can be used to isolate the equipment or installation characteristics that are prime candidates for design improvement.

Specific Conclusions

In addition to the general conclusions discussed previously, the following specific research conclusions appear relevant:

1. Interaction terms have improved the predictive strength of some regression models. The current trend to establish manpower, spares, and support equipment resource levels by separate analyses does not consider segnificant interactions between these resources. Future Air Force analyses should consider such interactions.

2. The initial design of support equipment will have a significant effect on the spares and manpower resource levels required for the weapon system. Early trade studies should be performed on these interactions before a design is selected for a weapon system.

3. The support equipment interaction results for this study appear to be conservative, because the LCOM has limitations in handling on-aircraft support equipment. However, this is not a sufficient reason for various Air Force commands to ignore support equipment in their baseline studies.

4. For peacetime, the two aircraft statistics, operationally ready and not operationally ready supply, are more realistic indicators of readiness for a weapon system than the sorties accomplished statistic, due to the normally low flying requirements.

5. Peacetime requirements are unique when compared to wartime. Therefore peacetime studies should be performed separately from wartime studies. The major advantage of the peacetime study is that it can be validated. Then, wartime results can be related to those of peacetime, for greater predictive value.

6. Cannibalization will have a greater impact on results than indicated herein, if supply percent fill-rate for baseline conditions is not held at 100 percent.

7. Deferred maintenance was not considered a significant variable for the F-15 weapon system. However, for studies involving aircraft with a mix of air-to-air and air-to-ground missions, this variable should be considered.

8. Extreme care should be used in relating these research results to the F-15 weapon system without knowledge of the LCOM. For example, the operationally ready statistic does not include aircraft that are being preflighted or that are flying; hence, the number of flyable aircraft are greater than indicated by the operationally ready statistic.

RECOMMENDATIONS

Public Law 95-79, FY 1978 Authorization Act, requires that "The Budget for the Department of the Congress for the fiscal year 1979 and subsequent fiscal years shall include data projecting the effect of the appropriations requested for material readiness requirements." A 2 November 1977 Secretary of Defense (SecDef) memorandum recognized that the needed measurement and analysis capabilities were beyond the state of the art, but directed that they be developed. Senate Armed Services Committee Report 95-826 on the FY 79 appropriations reiterated the requirement to relate funding to readiness assessment and improvement.

A methodology is needed to show the marginal change in sortie generation of a unit of tactical aircraft in the combat surge environment as a function of differing levels of the manpower, spares, and support equipment available to the unit when committed to combat. These unit resource levels must be translated into funding levels for the Force Structure in the budget and the Program Operational Memorandum (POM). This methodology would be used to assist in balancing resources across weapons sytems, and to satisfy the Congressional mandate that support resource funding be related explicitly to levels of readiness. In this context, readiness is defined as the number of sorties that can be generated during the initial surge phase of air operations. The method should be based on established data bases where possible, and not require excessive time or cost to generate information in the desired format. The methodology should also be capable of accommodating changes in scenarios and support concepts and of providing sensitivity output within 24 to 48 hours maximum turnaround. Specifically, based on this research's sensitivity analyses describing a sustained peacetime operation (e.g., the peacetime sortie effectiveness analysis illustrated in Figure 7 based on the developed regression models), a readiness assessment on a current operational fighter should be performed concerning capability for initial surge.

The Air Force maintains validated LCOM data bases on major tactical aircraft, in accordance with AFR 25-8. Aircraft systems currently covered include F-4E, RF-4C, F-4G, F-15, F-16, F-111F, EF-111F, A-10, E-3A, and C-130E. LCOM is used to establish resource requirements in relation to sortie generation capability. However, these models and data bases include extensive detail needed for planning specific resource authorizations and involve lengthy computer run times. This detail may not be required for assessing the gross impact of a total support budget. Using the methodology developed herein as source material, methods/procedures can be developed for reducing/condensing the amount of detail to the minimal essential information necessary to relate spares and manpower to sortie generation by simulation. These procedures can then be modified for application to the other systems.

In addition to the above recommendation that the next logical step for readiness assessment is to develop models of interaction between spare, manpower, and support equipment for a wartime surge environment, it should be noted that several essential variables to LCOM simulation were held constant in this study. Hence, the following additional studies should be considered for future models of interaction:

Unit Size - This study considered the interactions between the manpower and spares to support a 72 UE wing. However, optional study parameters are two different size wings:

1. A 72 UE wing capable of deployment to two, separate, self-sustaining operational locations with strengths of 48 UE and 24 UE.

2. A 54 UE wing capable of deployment to separate, self-sustaining operational locations of 36 UE and 18 UE strength.

Organizational Structure - For this research, the wing maintenance structure was that prescribed in AFM 66-1. Production-Oriented Maintenance Organization, POMO, concepts should be considered for future studies.

Logistics Composite Model - Support equipment resources logic for on-aircraft maintenance should be improved to avoid selecting more support equipment than is required for parallel maintenance tasks. Revisions in the model should also be considered for cannibalization of parts within the shops.

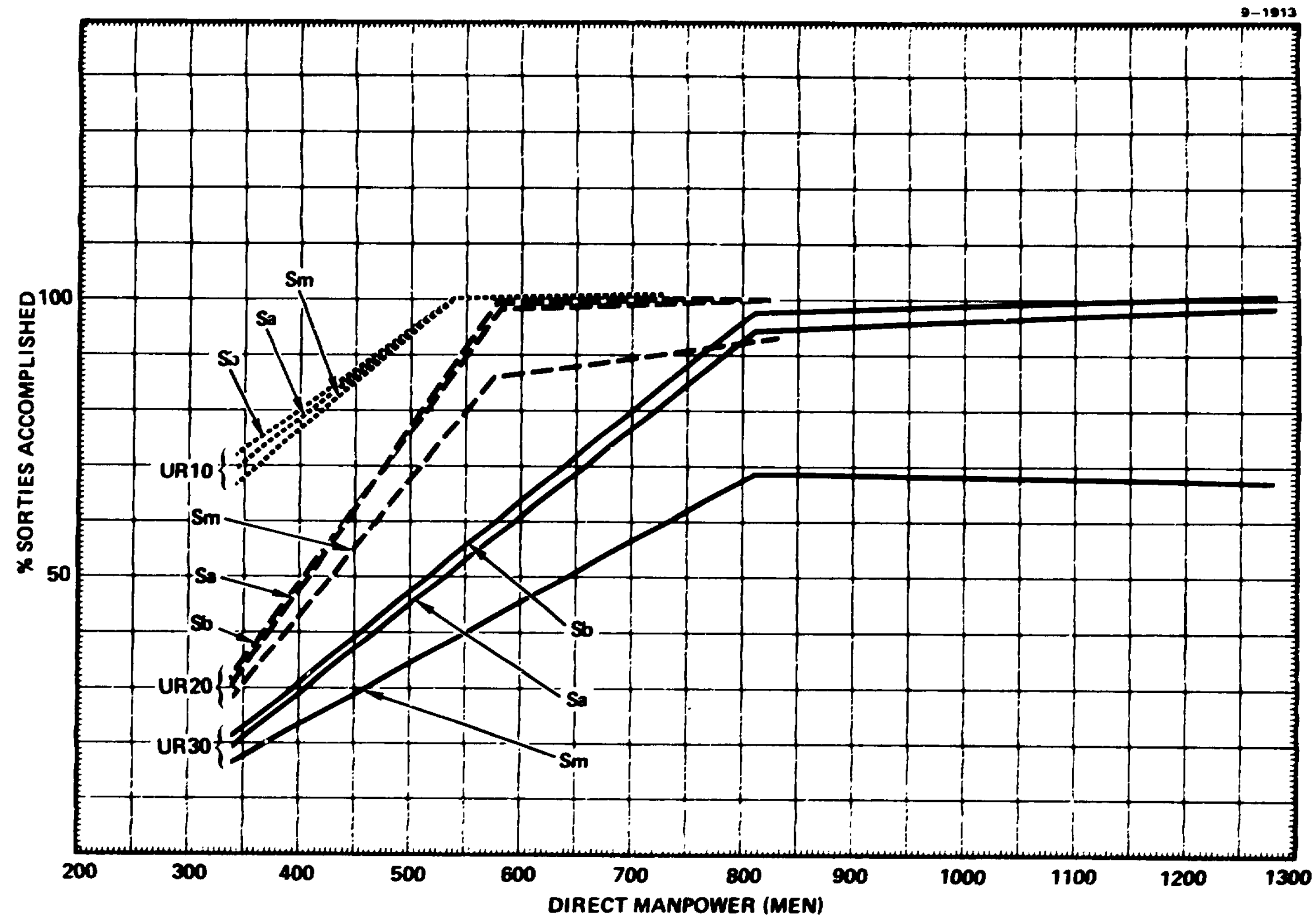

FIGURE 7 PERCENT SORTIES ACCOMPLISHED VERSUS DIRECT MANPOWER

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ABBREVIATIONS AND ACRONYMS

AARD	Air Refueling Day
AARN	Air Refueling Night
ACT	Air Combat Tactics
AFBS	Air Force Bases
AFDT&E	Air Force Development Testing and Evaluation
AFHRL	Air Force Human Resources Laboratory
AFIT	Air Force Institute of Technology
AFLC	Air Force Logistics Command
AFM	Air Force Manual
AFMEA	Air Force Management Engineering Agency
AFMSMET	Air Force Maintenance and Supply Management Engineering Team
AFR	Air Force Regulation
AFSC	Air Force Speciality Code
AFSC	Air Force Systems Command
AFTEC	Air Force Test and Evaluation Center
AFTO	Air Force Technical Order
AIS	Avionics Intermediate Shop
ASD	Aeronautical Systems Division
CONUS	Continental United States
DACT	Dissimilar Act
DART	Tow Target - Gun
DEP	Deployment
DO	Deputy Chief of Staff, Operations
DoD	Department of Defense

ABBREVIATIONS AND ACRONYMS

E	Mutually Exclusive Probability
ECMD	Electronic Countermeasures Day
ECMN	Electronic Countermeasures Night
FMC	Full Mission Capable
G	Nonmutually Exclusive Probability
GCC	Graduated Combat Capability Concept
GNP	Gross National Product
HQ	Headquarters
IAF	Intercept Alert Force
INST	Instrument Check
INT	Intercept
IR	In-Flight Refueling
LG	Logistics
LCOM	Logistics Composite Model
LRU	Line Replaceable Unit
MAC	Material Air Command
MDC	Maintenance Data Collection
MDS	Mission-design-series
Mod-Metric	Modified Multi-Echelon Technique for Recoverable Item Control
MMICS	Maintenance Management Information and Control System
MMM	Maintenance Manpower Model
MMH/FH	Maintenance Manhours per Flight Hour
MSBMA	Mean Sorties Between Maintenance Actions
NMC	Not Mission Capable

ABBREVIATIONS AND ACRONYMS

NMCS	Not Mission Capable Supply
NORS	Not-Operationally Ready Supply
NNMI	Night Intercept
O&M	Operations and Maintenance
ORI	Operational Readiness Inspections
PMC	Partial Mission Capable
PMCB	Partially Mission Capable Both (Maintenance and Supply)
PMCM	Partially Mission Capable Maintenance
PMCS	Partially Mission Capable Supply
POM	Program Operational Memorandum
POMO	Production-Oriented Maintenance Organization
RPV	Remotely Piloted Vehicle
SAC	Strategic Air Command
SECDEF	Secretary of Defense
SNMCB	Scheduled Not Mission Capable Both (Maintenance and Supply)
SNMCM	Scheduled Not Mission Capable Maintenance
TAC	Tactical Air Command
TFW	Tactical Fighter Wing
UNMCB	Unscheduled Not Mission Capable Both (Maintenance and Supply)
UNMCM	Unscheduled Not Mission Capable Maintenance
UE	Unit Equipped
UR	Utilization Rate (Flying Hours per Aircraft per Month)
USAF	United States Air Force

ABBREVIATIONS AND ACRONYMS

USAFE	United States Air Force Europe
WSEP	Weapon System Evaluation Program
WUC	Work Unit Code
%	Percent